A Model for Near Surface Groundwater on Mars

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Objective

To use a model of near surface groundwater on Mars to study gully formation and near surface lava ice interactions.

Introduction

Since Percival Lowell first described his observations of the "canals of Mars" as irrigation ditches on a dying planet, people have dreamed of life on Mars. A key ingredient to such life is water. Mars may have been a warmer, wetter planet in the past, but the present day surface temperature and obliquity (the tilt of the Martian equator with respect to its orbital plane) of Mars are not suitable for liquid water. However, there may be places beneath the surface where life can exist, an idea supported by observations that suggest water at depth.

The Gamma Ray Spectrometer (GRS) aboard the Mars Odyssey Mission has mapped the distribution of epithermal and thermal neutrons across Mars, up to one meter below the surface. The Hydrogen atom, being of similar to size to the neutron, is very efficient at creating thermal neutrons, so where large amounts of Hydrogen are present, few fast moving or epithermal neutrons exist, represented by the blue color in Fig. 1 (2002Sci…297…78M). The GRS only accounts for the H distribution in the top meter of the Martian regolith.

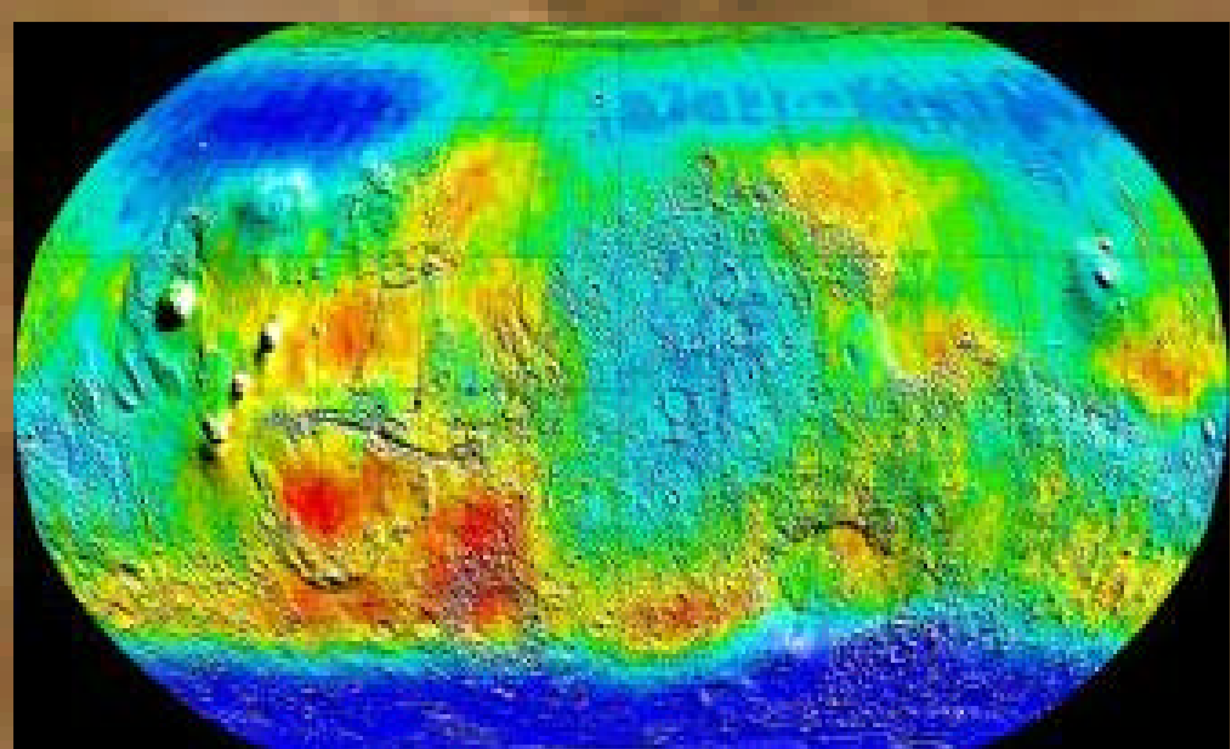


Figure 1. Epithermal Neutron Distribution
Blue: few neutrons, abundant Hydrogen
http://grs.lpl.arizona.edu/results/presscon2/

Gullies observed in high resolution pictures are one of the most important geological features on Mars that may indicate the presence of liquid water within geologically recent timescales [2000Sci...288.2330M]. The mechanism for gully formation is unknown, but groundwater seepage is the leading candidate (see Fig. 2).

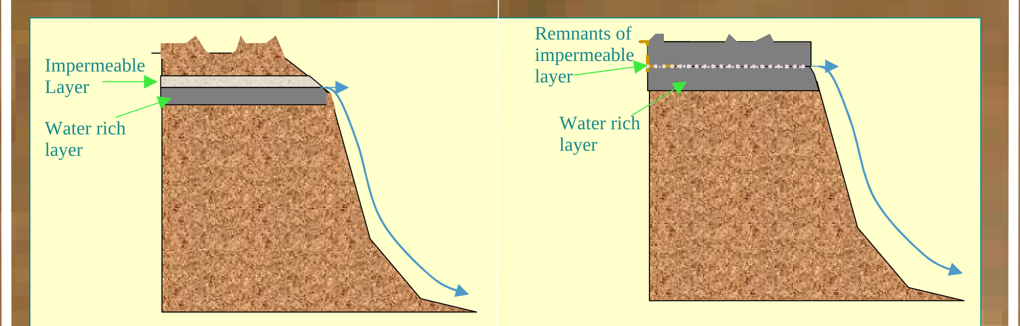
Gullies are found in many locations of Mars. In some areas there is apparent evidence for a recent water table at depth but no present day near surface concentration of water. A way to help solve the puzzle of gully formation is to determine the subsurface groundwater distribution on Mars.

The water distribution depends on a large number of factors, and models have been created to account for these. We choose to use the most sophisticated models of past and present day distribution of groundwater, published by Mellon & Jakosky (1993JGR…98.3345M [MJ93], 1995JGR…10011781M [MJ95], 1997JGR…10219357M [MJP97]).

My Contributions

- research and study Martian groundwater models
- examine equations and parameters used in models
- recreate models using IDL programming language
- (expected) run models to get subsurface water distribution for various locations on Mars
- (expected) relate water distribution results to geological features, especially gullies and recent lava flows

For Hale Crater and Noachis Terra	For the Polar Pits and Newton Crater



The impermeable layer creates pressure and causes the water to break out, run down slope and form gullies. This same impermeable layer prevents water/hydrogen from diffusing to the surface, resulting in a low detection of hydrogen.	At one time there was an impermeable layer that covered the water table. This created the pressure necessary to form the gullies, however, the impermeable layer has since been removed. This removal has allowed the water/hydrogen to diffuse to the surface and be detected.

Figure 2.Two Possible Methods of Gully Formation
E.L. Frey, *Water on Mars*, International Science and Engineering Fair, Cleveland, Ohio 2003

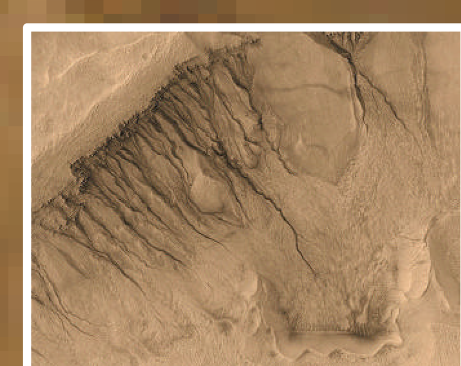


Figure 3. Gullies in Newton Basin at 39.0°S, 166.1°W
http://mars.jpl.nasa.gov/mgs/msss/camera/images/june2000/

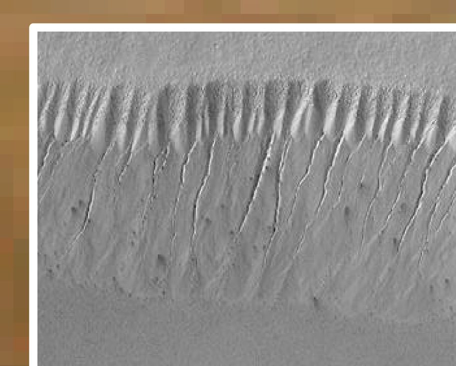


Figure 4. Gullies at 70.7°S, 355.7°W
http://mars.jpl.nasa.gov/mgs/msss/camera/images/june2000/

Gully Observations

2000Sci...228.2330M

Gullies are found:

- Preferentially poleward facing (~ 2.5:1) rather than equatorward facing
- At mid to high latitudes, ~30 to 70 ºN and S
- With shallow depths of origin, top ~100 to 500 meters of slopes
- To be geologically young (20 yr to 1 Myr)
- In a variety of topographical features:
  - simple scarps
  - mesas
  - knobs
  - crater walls (see Figs. 3 & 4)
  - central peaks

Gully Shape (see Fig. 5) (2003Natur.422...45C)

- A source region: alcove ~ 200 m wide
- V shaped channels leading from the alcove: ~ 100 m wide
- Depositional Fan Apron
- Typical dimensions: 20 m wide, 500 m long, 10 m deep

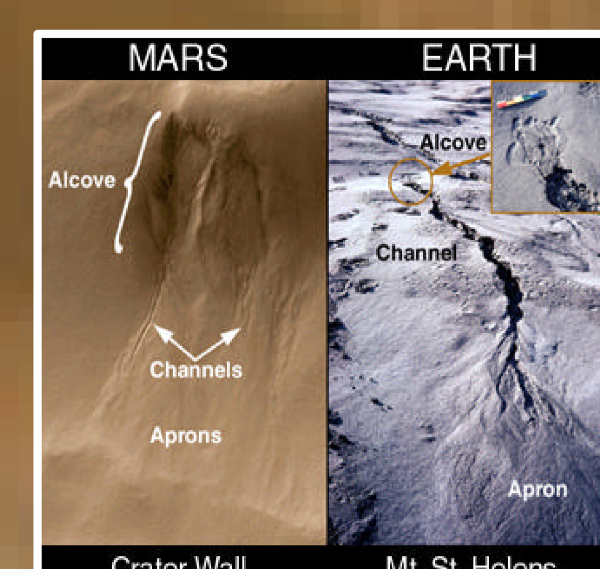


Figure 5. Gully located at 54.8°S, 342.5°W
Area = 1.3 km wide, 2 km long
http://mars.jpl.nasa.gov/mgs/msss/camera/images/june2000/

The Model

Michael Mellon, Bruce Jakosky, and coauthors have developed models to map the distribution of nearsurface water on Mars (MJ93, MJ95, MJP97). MJ93 explores water within the top few centimeters of the surface. It includes a Thermal Diffusion (TD) Model and a Molecular Diffusion (MD) Model. The MJ93 TD Model calculates the vapor saturation density, the mean average surface temperature, and the subsurface temperature as a function of depth z for 2° by 2° latitude x longitude boxes between 60 °N and 60 °S. The MJ93 MD Model provides equations for molecules of water vapor diffusing through CO_2 gas. It calculates the ice content of the Martian regolith as a function of time and depth. MJ95 determines the atmospheric column abundance of water as a function of Mars' obliquity. MJP97 offers two models, a Non Equilibrium (NEq) Model and a Steady State (SS) Model. The SS Model maps the distribution of ice forming a steady state layer a depth z below the surface of Mars (see Fig. 6). See Table 1 for our Model Parameters.

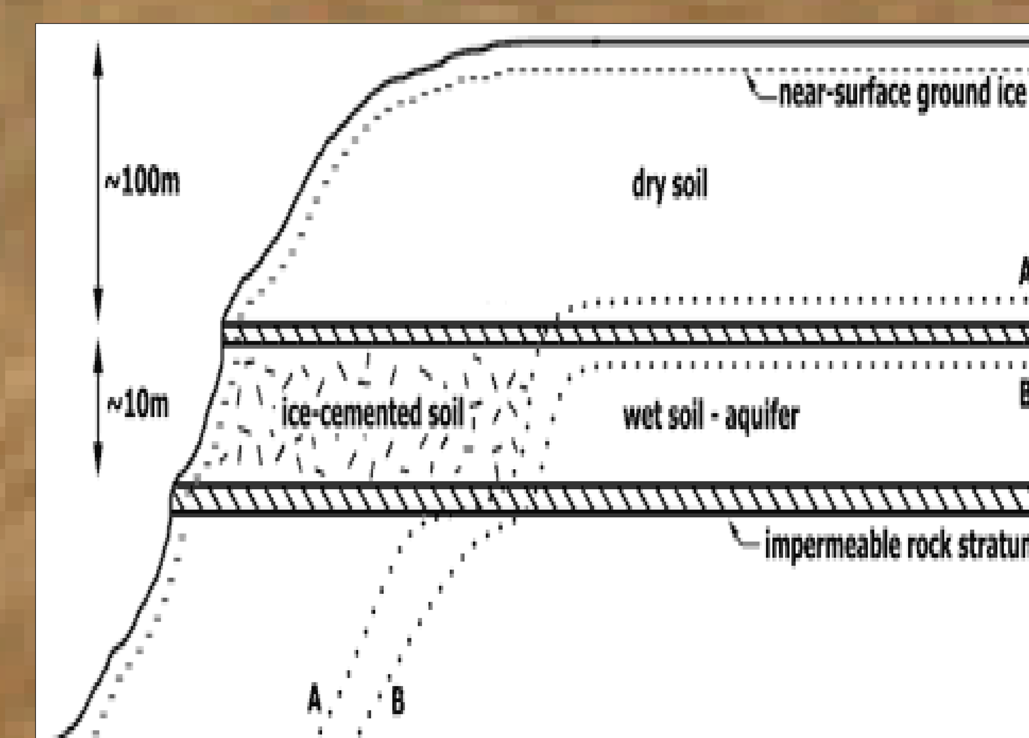


Figure 6. Model of Trapping and Freezing Groundwater leading to Gully Formation
A & B: Melting Isotherms at different obliquities
2001JGR...10623165M- Fig. 11

Future Plans

We plan to explore a range of parameters corresponding to particular situations of interest. Examples include a thick ice layer (10s of m) at substantial depth (100s of m) and a water rich near surface layer overlain by a recent (hot) lava flow. We are interested in determining how a steady state ice layer reacts to the presence of molten lava above it and the timescales over which it might become completely desiccated.

MJ93

Includes:
· geographic variations in albedo
· geographic variations in thermal inertia
Assumes:
· condensation of water from the atmosphere is the only source of water in the regolith
Ignores:
· effect of CO_2 driven water vapor transport through the regolith
· a geothermal temperature gradient near the surface of Mars

TD

Includes:
· latitudinal changes in insolation
· solar heating effects
· atmospheric thermal radiation on surface
· seasonal CO_2 frost
Assumes:
· the surface is vertically homogeneous
· surface thermal and physical properties remain constant over 10^5 year timescales
Ignores:
· any geothermal flux
· long term time dependent effects of subsurface thermal properties
· long term time dependent effects of CO_2 frost

MD

Includes:
· Normal Diffusion, gas gas collisions dominate
· Knudsen Diffusion occurs when gas molecule pore wall collisions dominate
Assumes:
· straight round pores
· a regolith completely devoid of water
· the top layer of the ice table interacts with the atmosphere
· the bottom layer lies above a nonporous layer
Ignores:
· diurnal surface temperature changes

MJ95

Includes: spatially variable atmospheric water content

MJP97

NEq

Assumes:
· the regolith is initially saturated with ice down to 200 meters
· there is no resupply of water from a deeper source.

SS

Assumes:
· the amount of water lost to the atmosphere through diffusion and sublimation is balanced by water diffusing and recondensing from a deeper water supply

Table 1. Sample Model Parameters

Symbol	Parameter	Value	Units	Ref
T_s	Mean surface temperature	220	K	1
e	Porosity	0.4		2
?	Bulk regolith density	1680	kg/m^3	1
dT/dz	Geothermal temperature gradient	0.15	K/m	1
?	Obliquity*	25.19	Degrees	2
y_v	Water vapor mixing ratio	0.0003		3
r	Mean pore radius	10	pr µm	1
C	Specfic heat of dry soil	837.36	J/kg K	1
t	Tortuosity	3		1
P	Ambient surface pressure	610	Pascals	1
n_{atm}	Atmospheric vapor density*	10	pr µm	1
k_0	Ice free thermal conductivity	0.3	W/m K	4

* of present day Mars
Refs: 1. MJ93, 2. MJ95, 3. http://laserweb.jpl.nasa.gov/planetaryinstruments/mirls.html, 4. MJP97

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